Planes, trains, and cars—the United States has traditionally been a nation on the go, highly dependent on efficient and reliable transportation. But as the 21st century approaches, people are finding their commutes by automobile longer and more congested, and often downright dangerous, with nearly 40,000 traffic fatalities each year.[1] In fact, the Federal Highway Administration forecasts that the number of vehicles on the road will rise 50 percent by the year 2005 over the 1988 figures, and the typical commuter's delay will rise from 15 minutes to about 1 hour.[2] And we are finding travelers more dependent on air travel to conduct routine business, creating new financial incentives for the airline industry to maintain the performance of its fleets and keep them running on time.

Many types of advanced technologies, such as electronics and materials, can improve the performance and safety of transportation systems. For example, innovative sensors can be used to prevent car collisions. High-temperature microelectronics can improve the performance, fuel consumption, and lifespan of aircraft by monitoring and controlling critical elements of jet engines, such as temperature, pressure, thrust, and fuel flow. And new material processes can make automobile and airplane parts more durable at lower costs. Ultimately, advanced technology will help improve the reliability of transportation systems, eliminate traffic congestion and delays and—most important—save lives.

Today's market. Automobile and aircraft manufacturers see signs that the transportation industry is beginning to grow after leveling off in the early 1990s. In one example, sales of passenger cars and light trucks in the Unites States totaled 15.06 million units in 1994, up 8.4 percent from 1993.[3] In another, jet aircraft makers are expecting $1 trillion in sales over the next 20 years, owing to growing passenger traffic, aging fleets that need replacement, and a return to profitability of the whole airline industry.[4] Technology is even allowing individuals to plan their own road trips right on their home computers, choosing from several options such as fastest, most scenic, or shortest routes. About 750,000 people purchased travel-planning software last year, and this market is growing rapidly. In 1994, sales reached $30 million, up 250 percent from 1993.[5]

Tomorrow's opportunity. BMDO's R&D in materials and advanced sensors has produced many innovations for ballistic missile defense systems. These innovations have been incorporated into new technologies that can help the transportation industry to improve safety, increase equipment performance, reduce congestion, enhance mobility, and minimize environmental damage. The following section describes seven such examples.

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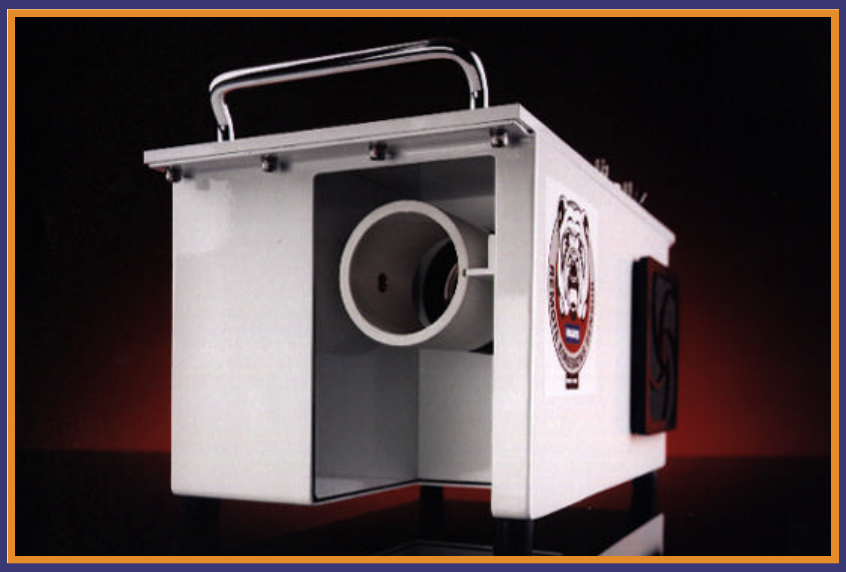
[1] Smart Solutions…S. Taylor; *American City & Country*, September 1994, p. 48.

[2] Smart Cars and Smart Highways…M. Fiseheti; *Photonics Spectra*, November 1994, p. 77.

[3] *Industry Surveys*, Standard and Poor's, April 27, 1995, p. A-96.

[4] Business Bulletin: A Special Background Report on Trends in Industry and Finance…*Wall Street Journal*, June 22, 1995, p. A-1.

[5] Travel Software Offers Info for the Highway…*Wall Street Journal*, May 12, 1995, p. B-11



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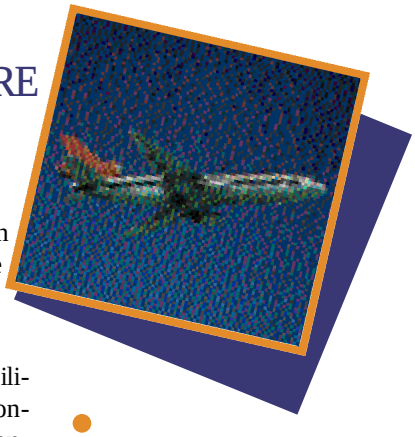
TRANSPORTATION

Rad-Hard Technology Breaks Temperature Barrier For Microelectronics



SSEC is supplying HOTronics™ sensors to three jet turbine engine manufacturers for testing in the next-generation control systems of commercial and military jet turbine engines.

Manufacturers of aircraft engines need to mount sophisticated microelectronics directly on engines to improve control, efficiency, and performance. But current devices cannot bear the heat generated during engine operation. When exposed to temperatures above 125°C for long periods, they become unreliable and eventually fail.

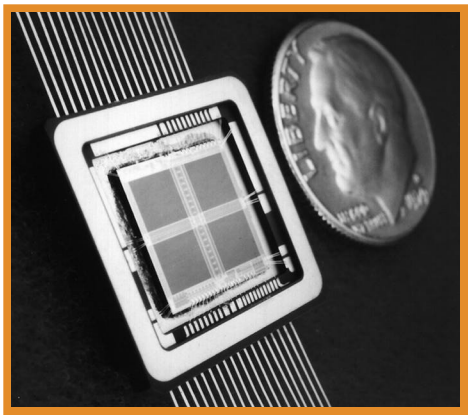
Honeywell, Inc.'s Solid State Electronics Center, or SSEC (Plymouth, MN), has developed a silicon-on-insulator (SOI) technology that allows its HOTronics™ sensor and HTMOS™ electronic products to endure high temperatures. SSEC is supplying HOTronics™ sensors to three manufacturers of jet turbine engines for testing in the next-generation control systems of commercial and military jet turbine engines. The new sensors can reliably monitor critical elements such as temperature, pressure, position, and fuel flow for improved turbine engine control.

HONEYWELL'S HIGH-TEMPERATURE MICROELECTRONICS USE BMDO-FUNDED SILICON-ON-INSULATOR TECHNOLOGY TO WORK BETTER AND LAST LONGER IN HIGH-TEMPERATURE ENVIRONMENTS.

SSEC is also teaming with a major automotive manufacturer to develop a sophisticated V-8 engine management system. HOTronics™ sensors are being tested to measure the position of engine valves and monitor fuel flow. Such functions can help the engine management system reduce the amount of pollutants being emitted.

In addition to engine management, SSEC's high-temperature sensors and electronics have immediate applications in oil field and industrial instrumentation. The devices also may have potential in space, commercial nuclear power, power conversion, and plastics/composites forming applications.

SSEC expects the markets for high-temperature electronics and sensors to grow from $20 million in 1994 to $60 million by the year 2000. It will also target the market for high-temperature automotive sensors operating above 170°C, which is predicted to grow from $5 million to $20 million in the next 5 years.



Pictured above is a small silicon-on-insulator CMOS device next to a dime. Honeywell's sensors, based on this technology, can operate at temperatures as high as 225° C—100° C greater than competing devices.

About The Technology

With funding from BMDO, SSEC developed microelectronic device technology to make complementary metal-oxide semiconductor (CMOS)-based microcircuits immune to high levels of radiation by employing SOI materials. SSEC found that, with little or no modification, SOI CMOS technology could also be used to help microelectronics operate at temperatures up to 225°C—100°C greater than competing devices. SOI CMOS technology eliminates the p-n junction of a conventional ion-implanted sensor. This junctionless sensor provides robust fail-safe operation in virtually any type of hostile environment. The electronic components for the sensors are fabricated using Honeywell's high-temperature oxide-isolated process.

SSEC's first product line, HOTronics™, features several high-temperature sensors used for measuring pressure and magnetic fields. The second line, HTMOS™, includes two high-temperature electronic devices—the Quad Operational Amplifier and the Quad Analog Switch—used in analog signal conditioning for sensors and for analog control functions. Additional HTMOS™ devices will be under development through 1996.

New Carbon-Carbon Deposition Process Could Lower Brake Costs

This Boeing 737 uses airplane brakes by B.F. Goodrich. Future brakes, which will be strong, lightweight, and capable of significant thermal conductivity, may be made of a carbon-carbon composite using a process originated by BMDO.

Heat plays a significant role in the wear of materials. It wears the brakes of aircraft and automobiles, and it degrades the materials used for engines and exhaust systems. Therefore, materials that can resist high temperatures, such as carbon-carbon composites, have become increasingly important; unfortunately, these materials are often very costly and time-consuming to make.

Sioux Manufacturing Corporation (Fort Totten, ND) has developed a new carbon-growing manufacturing method that may soon reduce the production costs of such high-temperature composite materials—reductions that may later translate to lower consumer costs. Carbon-carbon materials can be used in everything from airplane and automobile brakes to the circuit boards of high-density electronic equipment.

Sioux Manufacturing has recently teamed with B.F. Goodrich to continue work on the composite. B.F. Goodrich plans to integrate Sioux's carbon-growing process into its aircraft brake manufacturing to improve its existing product line.

Sioux Manufacturing has teamed with B.F. Goodrich, which plans to integrate the carbon growing process into its brake manufacturing business.

Carbon-carbon materials processing was first developed for the nose cones of re-entering space vehicles. Through a BMDO SBIR, Sioux Manufacturing has successfully tested a new method for growing the carbon before it is applied to the underlying carbon fibers that together comprise the carbon-carbon composite.

The material can be used as the fins at the ends of the circuit board to carry heat away from electronic components. It could also replace the fiber epoxy currently used as the substrate of circuit boards, as it would be able to transfer heat out of the housing much faster than the conventional material can.

In satellites, the expansion and contraction of materials in the extreme temperatures of space can lead to material failure, such as cracking or bending. The new carbon-carbon material has a very stable coefficient of thermal expansion between the carbon and the fibers, so that satellite components or housings would be better protected from temperature fluctuations.

Pictured above are aircraft brake disks, components that may benefit from Sioux's materials technology.

About The Technology

Carbon-carbon composites consist of carbon fibers surrounded by a matrix of carbon. Sioux Manufacturing's process for making these composites uses a magnetite catalyst, which is a ferrofluid, to increase the decomposition and deposition reaction rate of methane gas. At the end of the process, the methane gas deposits itself as carbon on the preformed fibers. The new technique increases deposition speed by a factor of three and therefore may considerably reduce the cost of producing the composite.

The first experiments with the new process were performed using only laboratory-scale samples. B.F. Goodrich is now working with Sioux Manufacturing to verify that the rate enhancement will carry over to large-scale samples.

Power R&D Improves Materials Processes For Auto Industry

Automobile manufacturers are looking for new ways to quickly produce automotive parts, such as the gears in automotive power trains that meet demanding performance requirements. Traditional manufacturing methods, such as using high-pressure forming and punch presses on blanks, are quick but they leave jagged edges and rough surfaces that require postmachining—a time-consuming process.

One alternative to traditional methods is powder metallurgy, a process in which metal powders are compacted into smooth shapes, eliminating the need for polishing and finishing. Powder metallurgy is used for some components in the automotive industry, but it has not yielded the densities required for very rugged, high-performance components. Such components are still stamped or forged, making them costly to manufacture.

Applying power technology from a BMDO SBIR, IAP Research, Inc. (Dayton, OH), has developed a technique called dynamic magnetic compaction (DMC) that makes powders used in powder metallurgy dense enough to be used for high performance automotive parts. The process both speeds manufacturing and improves the quality of the parts, thereby saving the automotive industry money and time.

IAP RESEARCH MAY SAVE AUTO MAKERS TIME AND MONEY BY SPEEDING UP THEIR PARTS MANUFACTURING CAPABILITIES.

IAP is leading an $8.4 million cost-shared Advanced Technology Program project awarded by the National Institute for Standards and Technology to further develop DMC. IAP has teamed with General Motors Powertrain Division and Zenith Sintered Metal Products; the team will contribute $4.3 million to the project and is focusing on complex automotive transmission components. IAP plans to produce and sell the electromagnetic parts-making equipment to car parts manufacturers such as its joint venture partner, Zenith Sintered Metal Products, which will then sell parts to General Motors and other major manufacturers.

IAP Research's process has been used to form metal rods, as shown above. Powder is loaded into a copper tube (right) and the compaction process forms the powder into a nearly fully-dense rod (left).

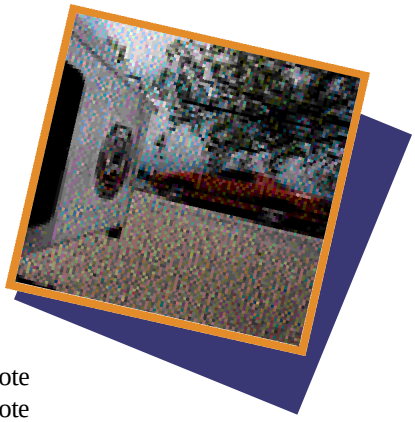
Researchers at IAP believe manufacturers using DMC can make a complete gear, including the teeth, in less than a second. Starting with powdered steel, the process uses high-pressure pulses generated by an electromagnet to compress the powder into a die to make a solid part. The pressures are equivalent to those under a 4,000-pound weight supported on a three penny nail. A second step in the process sinters or "bakes" the part to strengthen it. BMDO originally funded IAP's development of electromagnetic power supplies for rail gun accelerators used in space to destroy enemy missiles. This power technology is central to the compaction technique.

About The Technology

In DMC, high currents are passed through a compactor coil from an electromagnetic power supply system. The metal powder is enclosed in a confining container and placed at the center of the compactor coil. For electrically nonconducting powders, the confining container has to be conductive; for conductive powders, this restriction does not apply. The currents in the compactor coil generate magnetic fields that produce magnetic pressures on the powder, consolidating it. This pressure is directed radially inward on the powder. While conventional techniques apply pressure from the top and the bottom, the IAP method applies pressure from outside in, along the whole length of the part.

Pulsed magnetic forces have two advantages over mechanical forces: (1) very high forces can be generated with a small, low-cost system; (2) the forces can be applied with great precision in time and space. The short pulses permit high repetition rates while offering the possibility of dynamic effects in the powder; that is, the particles compress and heat during the very short pulse, softening and becoming more plastic. This phenomenon may increase the density of the part.

Smog Sensor Detects Pollution-Prone Cars



Smog Dog™ can screen thousands of vehicles per day at no inconvenience to today's busy motorists.

National studies indicate that roughly 20 percent of cars driven today account for about 80 percent of automotive pollution during normal operation.[6] Unfortunately, many of these cars can remain on the road for years because authorities have great difficulty detecting them through the idle test or visual inspection.

State and local governments are investigating new ways to monitor emissions, one of which is remote sensing. Often associated with satellite monitoring of the environment and ground structures, remote sensing can also be used on the ground to detect automobiles with high emissions levels.

In conjunction with Hughes Aircraft Company, Santa Barbara Research Center, or SBRC (Santa Barbara, CA), is selling an infrared (IR) remote sensing device called Smog Dog™, which "sniffs out" the biggest offenders on roads and highways. The device can automatically measure tailpipe emissions by detecting changes in the intensity of IR "light" beamed across the road. To identify the car, SBRC also offers an Automatic License Plate Reader that can read and record alphanumeric characters from the video image of the license plate.

SMOG DOG™ UNITS BUILT BY SANTA BARBARA RESEARCH CENTER RELY ON INFRARED PHOTODETECTORS TO IDENTIFY CARS AND TRUCKS WITH HIGH EMISSIONS ON AMERICA'S HIGHWAYS.

SBRC recently delivered six Smog Dog™ units to the Arizona Department of Environmental Quality, which began a vehicle emissions testing program in the Phoenix area on May 15, 1995. Owners of vehicles identified as high polluters receive letters requesting voluntary inspection/repair action. If the same vehicle is identified again as a high emitter, a second notice is sent requiring mandatory inspection/repair. SBRC has also sold several units to government agencies in Idaho, Canada, and Australia.

The smog sensor uses a modified device originally developed for BMDO's Heterojunction Interface Trap (HIT) program. HIT was designed to create mercury cadmium telluride IR detectors with reduced bias power requirements and very high sensitivity under low-temperature and low-background-flux conditions. BMDO needed these detectors for ballistic missile surveillance and tracking in the long-wavelength IR region.

In addition, SBRC has used its HIT detectors to create remote sensing instruments for the government. For NASA, SBRC developed several linear sensor arrays such as the Moderate Resolution Imaging Spectroradiometer to provide geophysical, atmospheric, chemical, and biological information on Earth. The company has also developed linear sensors, such as the multispectral thermal imager, for treaty-compliance applications.

Santa Barbara Research Center's infrared sensor passively measures automotive emissions when cars are being driven at speeds up to 65 miles per hour.

About The Technology

To detect pollution-prone vehicles, the van-mounted IR source on one side of the road directs a beam across the road—usually single-lane ramps to highways—to a sensor on the other side. When a vehicle breaks the beam, Smog Dog™ measures percentage concentrations of its exhaust gases, which include carbon monoxide, carbon dioxide, hydrocarbons, and nitrogen oxides. The IR sensor works by detecting changes in the intensity of the IR beam, which drops when the exhaust gases absorb some wavelengths. Meanwhile, a roadside camera takes a video snapshot of the vehicle. A computer in the van "reads" the exhaust gas concentrations and the letters on the license plate. At the end of the day, the van downloads its data into State computers, which match the information with auto registration records to pick out vehicles whose pollution exceeds allowed levels for their size and model year.

[6] *Remote Sensing Information* (fact Sheet), Arizona Department of Environmental Quality, January 1995.

Sensor Paves Way For Collision Avoidance Capabilities

One of the applications for Picometrix's technology is collision avoidance.

Picometrix, Inc. (Ann Arbor, MI), is using BMDO-funded technology to develop a sensor for a collision avoidance system to detect obstacles in the road that could potentially harm an automobile. Called the SOTA, or sampling optical temporal analyzer, this small solid-state chip could receive signals and send them to a system that redirects the automobile. Picometrix was awarded a $1.4 million research project with the U.S. Army Tank–Automotive Command (TACOM) to continue this work on a picosecond laser radar sensor. The company is currently collaborating with other partners.

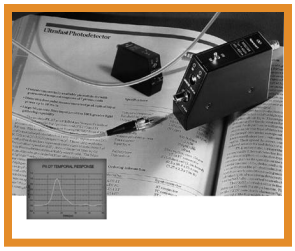
Further into the future, this technology could also help increase highway capacity in an intelligent transportation concept called platooning. In this concept, a group of vehicles could travel down a highway inches apart at a fixed speed, reducing travel times and the risk of accidents. The SOTA could help distance the vehicles properly. Picometrix's technology may also be used to optically recognize bar codes on highway signs, allowing this information to be displayed on the driver's dashboard. This capability could eliminate the need for traditional street signs and/or help prevent drivers from missing their turnoffs.

> THROUGH A LICENSING AGREEMENT, PICOMETRIX'S PHOTODETECTORS ARE NOW WIDELY AVAILABLE THROUGH NEWPORT CORPORATION.

Operating at least 100 times faster than existing compact sensor technology, the SOTA is a photodetector and a photogate on one chip. It is as sensitive as a conventional photodiode but responds much faster. The SOTA is expected to be on the market by June 1996.

Through a licensing agreement, Picometrix is selling its photodetectors (an intrinsic part of the SOTA) to the scientific community. The devices are widely available through Newport Corporation—one of the largest distributors of laboratory laser equipment. Newport offers two Picometrix-developed products, the PX-D7 and the PX-D14. With a response time of 7 picoseconds, the PX-D7 is the fastest photodetector available commercially, costing less than $6,000. It is easier to use and can gather light 100 times more efficiently than competing technologies. The PX-D14 is a slower version of the device with a response time of 14 picoseconds and costs less than $4,000.

Spinning off his own company, Steve Williamson, principal investigator for this BMD research at the University of Michigan's Ultrafast Science Optical Laboratory, formed Picometrix roughly 4 years ago to productize his findings. With some manufacturing capabilities on a subsystem level, Picometrix continues to work closely with the university in its research. Picometrix has since received related BMDO SBIR funding.



The PX-D7, shown above, has a response time of 7 picoseconds and is the fastest photodetector available commercially.

About The Technology

As a result of BMDO-funded research at the University of Michigan, Picometrix demonstrated a photoconductive 1-picosecond photodetector, which can function as a detector at low optical intensities or as a switch at high optical intensities. As sensitive as a silicon photodiode, this fast version uses gallium arsenide as the active semiconductor. The arsenic-rich properties of the growth process ultimately make the photodetector highly resistive and responsive and contribute to its short carrier lifetime.

Using the technology's dual functionality, researchers have integrated the photodetector on the same chip as a similar laser-activated photogate. The photodetector can perform two functions, allowing 1-picosecond optical signals to be detected and processed without the ultrafast signal ever leaving the sensor chip. Together, the 1-picosecond photodetector and photogate form the world's fastest, most compact, ultrasensitive picosecond optical waveform analyzer. The output from this device is an electrical signal that can be measured using conventional electronics. It operates jitter-free and has an anticipated signal sensitivity as low as 1 picowatt and dynamic range exceeding 10^6.

Intelligent Software To Benefit Travel Industry

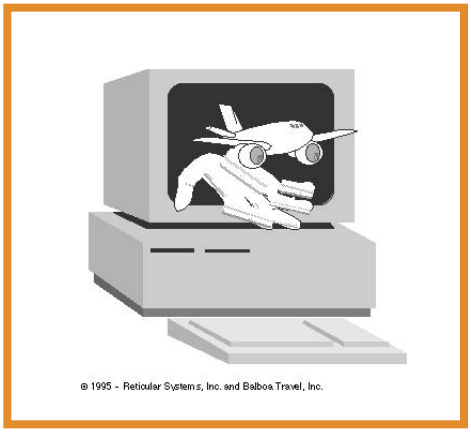
To cut costs, the airline industry is reducing commissions it pays to travel agencies. Such reductions, which will ultimately help make plane tickets cheaper, have forced travel agencies to get leaner, cutting services that flyers take for granted. For example, travel agencies may have to start charging more to pay for keeping records of frequent flier information, seating preferences, and other travel needs.

But while the travel agencies and airlines are cutting back, corporations are continuing to demand better travel management services. In addition to services such as reservations and ticketing, firms on the go need policy consulting, monitoring of adherence to travel policy, cost reporting, and information services and analysis.

Reticular Systems, Inc. (San Diego, CA), is developing a family of travel-related intelligent software that could significantly improve the way reservations are made and increase the efficiency of travel agencies. The products are designed to serve the major customer communities: travel agencies, corporate travel managers and travel arrangers, and mobile travelers. The core software will allow developers to enhance their application software products by adding reservation-making capabilities. The products could include commercial desktop productivity software, integrated office suites, on-line services, and CD-ROMs.

RETICULAR SYSTEMS IS BUILDING INTELLIGENT SOFTWARE PRODUCTS THAT ARE SMART ENOUGH TO BOOK AND CHANGE TRAVELER RESERVATIONS ON THE FLY.

To commercialize this intelligent software, Reticular Systems and a nationally ranked travel agency called Balboa Travel, Inc. (San Diego, CA), have formed a strategic alliance and are creating a new company. The new company, provisionally called Madison, is looking for equity funding from investors to finance continuing development, marketing, sales, and product support for the software. The products will be developed using AgentBuilder™, a software tool kit for constructing intelligent agent software. AgentBuilder™ has been developed using another tool called IntellAgent™. Both tools resulted from a feasibility study funded by BMDO.



Intelligent software could significantly improve the way travel reservations are made and increase the efficiency of travel agencies.

Under a NASA proposal, Reticular Systems hopes to build an intelligent electronic notebook for astronauts using the IntellAgent™. The notebook will also feature recent advances in voice recognition, speech synthesis, natural language processing, user modeling, and object-oriented databases.

In addition to creating software to automate travel reservations, early versions of AgentBuilder™ are being used to build products to retrieve information intelligently from large databases and for other information processing tasks. They are also serving as intelligent adversaries in computer-based games.

About The Technology

Intelligent agents allow computer users who do not know how different databases work to efficiently extract information from a whole network of them. The agents are therefore useful in any line of work where large, diverse data sets are needed to make complex decisions.

Unlike a simple search routine, an intelligent agent must carry out many complex functions. For example, an intelligent agent used in situation assessment must be able to sense the environment, assess the environment, develop plans for problem solution, execute the plan steps, and learn as the system interacts with the environment. It also must tolerate missing or incorrect information and reason in a way that meets rapidly changing demands.

New Sensor For Antilock Braking Systems To Improve Safety And Reliability

Once a car slides on ice or loose gravel, it is often too late for the driver to regain control. No matter how quickly the driver slams on the brakes or turns the steering wheel, the car is likely to spin out of control. If this happens, the driver faces one of the most hazardous forms of collisions—the side impact.

Applied Technology Associates, or ATA (Albuquerque, NM), is using magnetohydrodynamic (MHD) technology to improve the safety and performance of braking, steering, and handling systems. Using this technology, ATA has developed the MHD effect rate gyroscope (MERG) to measure the steady rotation in cars, planes, and satellites. By signaling that the car has begun to swerve right or left uncontrollably, the new sensor will help the antilock braking system's computer to engage front and rear brakes sooner and more effectively. This procedure will re-orient the car so that its front faces oncoming traffic or objects. Such positioning can saves lives, since front impacts are the least hazardous form of collisions.

APPLIED TECHNOLOGY ASSOCIATES' TECHNOLOGY WILL RESULT IN ADVANCED SENSING PRODUCTS FOR NEXT-GENERATION BRAKING, STEERING, AND RIDE STABILIZATION SYSTEMS IN VEHICLES.

MERG sensors are an attractive option for antilock braking systems because they can potentially be smaller, lighter, less expensive, and more energy efficient than current technology. The estimated cost of the compact sensor is less than $25 when the device is manufactured in high volumes. At this price, automotive manufacturers can afford to improve antilock braking systems, expected to be used in all U.S. automobiles by the year 2000.

The MERG sensor can also be applied in vehicle navigation systems that receive signals from satellites. The Army will soon be using MERG sensors to test a new land navigation system in its high-mobility multipurpose wheeled vehicle, which was heavily used during Desert Storm. MERG sensors may also be useful in areas such as attitude measurement and control for aircraft/aerospace, robotics, rotational equipment control, and machine diagnostics.

ATA has developed a family of angular rate sensors, shown above, which are based on the magnetohydrodynamic principle.

About The Technology

Magnetohydrodynamic sensors, which use the interaction between a conductive fluid and a magnetic field to measure angular motion, operate with great precision in diverse environments. These solid-state, hermetically sealed sensors range from shock detection devices that are as small as a dime and weigh just 7 grams to nanoradian measurement devices that resemble a small juice can. The sensors have been tested at forces 1,200 times that of gravity, and analytical predictions have shown they could withstand forces 50,000 times that of gravity.

ATA has developed two general classes of MHD sensors: passive and active. The passive sensors, which measure shock, vibration, and other time-varying motions, are sold commercially for applications in crash dummy testing and vehicle dynamic testing; they are also being evaluated for traction control systems such as antilock braking systems. The active rate sensors, including the MERG sensor, function like a gyroscope; they measure the steady motion of cars, planes, and satellites. ATA developed the basic technology underlying all of these sensors in a BMDO project to measure angular vibration in a space-based laser system.